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Investigation of wind characteristics and wind energy potential at Ras Ghareb, Egypt

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ABSTRACT

To study the structure of a coastal location «Ras Ghareb» on the Red Sea in Egypt, a measurement station with mast of 24.5 m has been established in a built-up area, near the seashore. First, a statistical analysis of the measured data over the period 2000–2005 was performed, including calculation of the wind speed power law index which was found to be 0.18 for Ras Ghareb area. Then, wind speed data was expressed at the height of (usually 10 m) which makes it directly related to the objective of those people working in the renewable energy sector. Therefore, the mean wind speeds, availability of data, seasonal variation and the distribution by the wind direction were studied to ascertain its potential for wind energy development.

The annual wind speed over this site varies from 8.3 to 9.8 m/s at 10 and 24.5 m heights, respectively. Most of the time 73% the mean wind speed in the ranges 5–10 and 10–17 m/s at 10 m. Also, higher winds of the order 10 m/s and more observed during summer months. The main wind direction is north–northwest sector (330°) for about 51% of the times during the year that makes it unique for installation of wind parks.

Second, numerical estimations to determine the seasonal power law coefficient and Weibull parameters at different heights from 10 to 100 m were carried out.

Finally, Rayleigh distribution and our method stated in Ref. [3] were adopted for defining the monthly wind power available at 10 m height for this region. It is emphasized that Rayleigh model is not appropriate and our method is more efficient for Ras Ghareb area. Where the expected mean of wind power density was found to quite high 360 W/m^2 per year at 10 m hub height, which makes this station likely candidates for wind power utilization.

It is appear from our analysis that Ras Ghareb region can be explored for generating the electricity. Where the monthly and annual pattern of wind speed matches the electricity load pattern of the location.

Contents

1. Introduction

The wind energy resource is very large and widely distributed throughout the world as well as in Egypt. To begin with, any country considering using wind electricity technologies must first evaluate its own wind regime to assess the potential of the installation of wind–electricity generation. It has long been recognized that the wind energy potential along the Gulf of Suez and the Red Sea is markedly higher than in other parts of Egypt – and most other parts of the North African deserts as well. Egypt has vast areas with wind conditions which are suitable for wind energy development. There are generally only scattered populations in these areas. The main obstacle for development, there is no industrial manufacture of wind turbines in Egypt so equipment and expertise must be

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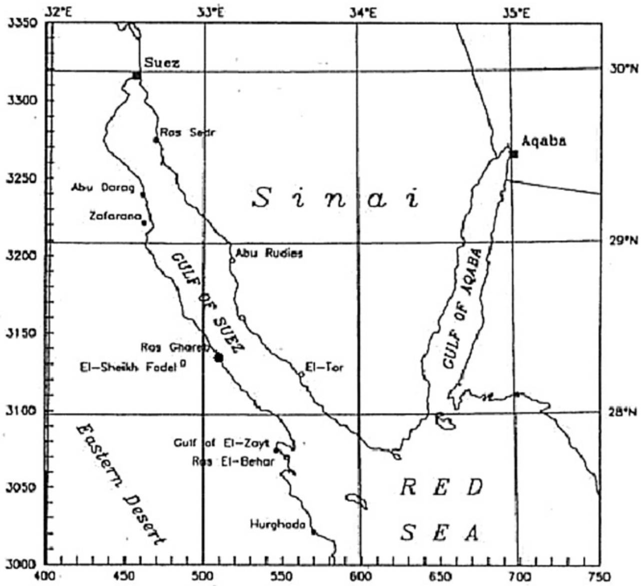

Fig. 1. Location of the measuring meteorological stations over Gulf of Suez and the northern Red Sea in Egypt; (•) indicates the location of Ras Ghareb station.

imported from other countries. Currently, Egypt produces electricity using wind farms at Zafarana, Gulf of El-Zayt and Abu Darag stations, which are located in the northern part along the Red Sea. Their electricity production presented to the country and due to an increase of needs Egypt exported these electricity to Jordan [1–3].

This note presents a first analysis of wind data for Ras Ghareb region on the east coast of Red Sea in Egypt, and provides a basis for a preliminary evaluation of wind power potential in the region.

2. Description of the site and measurement station

To study the structure of the coastal wind field on the Gulf of Suez in Egypt, a measurement station with mast of height 24.5 m, has been established about 6 km WSW of the town of Ras Ghareb. The distance to the coastline of the Gulf of Suez is also about 6 km in an east-northeasterly distance. There are no sheltering obstacles close to the «Ras Ghareb mast». The surface consists mostly of sand and gravel with a roughness length of less than 0.01 m. The map in Fig. 1 indicates the location of the station in northern region the east coast of Red Sea in Egypt. Where its grid coordinates (latitude 28°20′, Longitude 33°01′) and elevation is 56 m above the ground level.

Wind speed is measured with cup anemometers of the Risø-70, manufactured by the Wind Energy Department at Risø, Denmark. This anemometer features a light weight 3-cup rotor and is a sturdy, yet fast-responding anemometer. The calibration is linear with an offset (‘starting speed’) of approx. 2 m/s. The distance constant is about 1.8 m [4].

3. Wind speed and frequency distribution

The wind speed behaviour of a region is a function of altitude, season and hour of measurements. Generally, five years of records and weather watching is sufficient to predict the long-term seasonal mean wind speed to within an accuracy of 10% with a confidence level of 90% [5].

For this study, wind speed recording instruments are located at 24.5 m height above the ground level for a period 6 years (2000–2005) by the Renewable Energy Authority in Cairo, Egypt. This means that the quality of the recorded and published data does not reflect the calibration factor. In addition, it was also necessary to adjust the wind speed data to a height of 10 m in order to make it directly related to the objective of those people working in the renewable energy sector.

Over the last decades the effect of different heights on wind speed has been studied by many authors [5–7], and the relationship for computing the wind speed at a height of 10 m when measurements are taken at heights other than the standard 10 m is given as:

$$V_1 = V_2\left(\frac{H_1}{H_2}\right)^{\alpha} \tag{1}$$

where V_1 = the estimated mean wind speed at 10 m height, V_2 = the mean wind speed measured by the Renewable Energy Authority, Egypt at Ras Ghareb station, H_1 = the anemometer height, 10 m, H_2 = the anemometer height at Ras Ghareb station.

Recently, α is the roughness factor, this parameter is the wind speed power law index, which is considered to be 1/7 or 0.14, for surfaces with low roughness, as given by the one-seventh power law. The value of this coefficient varies from less than 0.10 over the tops of steep hills to over 0.25 in sheltered locations. In addition, the value of α in Eq. (1) depends on the time of the day, the wind speed level, the wind stability and the surface roughness. This value varies from 0.10 to 0.40 [8–10].

The simply computed roughness factor, α, which results from the wind speed measurements, recommended by many authors was used as follow [11–14]:

$$\alpha = \frac{0.37 - 0.0881\ \ln V_2}{1 - 0.0881\ \ln(H_2/10)} \tag{2}$$

By applying the available wind data for the station under study at 24.5 m height with the Eq. (2), it is evident that the corrected roughness factor for Ras Ghareb region has been found to be α = 0.18. So, the results of the above processes on wind speed are presented in Table 1. Mean monthly for measured wind speeds at 24.5 m height of the year with estimated values at H_1 = 10 m height are plotted in Fig. 2. Analysis the data of Table 1 and Fig. 2 lead to the following:

(1) This table shows that the wind speed at Ras Ghareb is generally high. Where the annual mean wind speed of the site is 8.3 m/s at 10 m height.
(2) From March to October strong trade winds observed and the drop in the average wind speed observed from November to February. The maximum value of monthly mean wind speed is 10.2 m/s during June and the minimum value is recorded at the station with 6.4 m/s during January.
(3) On the seasonal scale: Ras Ghareb’s wind climate is characterized by the trade winds during summer season in the range of 10 m/s. Additionally there are strong wind 8.3 m/s blowing at spring and autumn periods.

Table 1
Measured and calculated mean wind speed (m/s) for the years 2000–2005 of Ras Ghareb at 24.5 m and 10 m, respectively.

Mean wind speed	Month												Annual mean
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
v_{10}	6.4	6.6	7.9	8.3	8.8	10.2	9.5	10.0	9.7	8.5	6.6	6.6	8.3
$v_{24.5}$	7.5	7.8	9.3	9.7	10.3	12.0	11.1	11.7	11.4	10.0	7.8	7.7	9.8

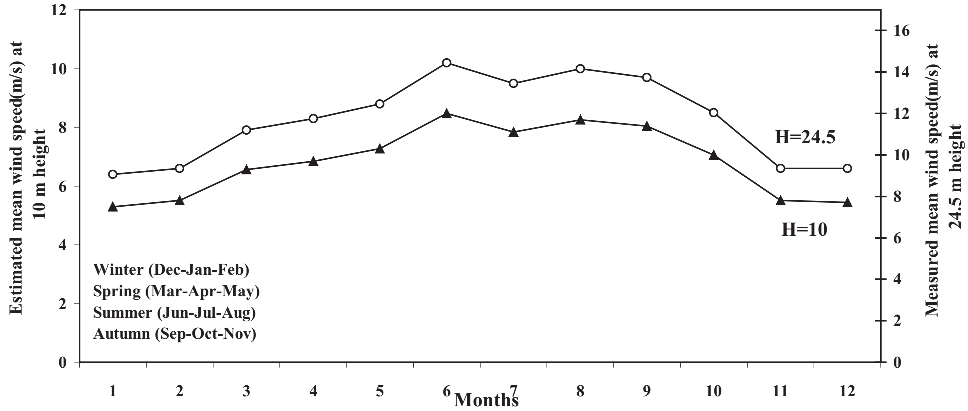

Fig. 2. Monthly variation of measured and estimated wind speeds of Ras Ghareb at different heights.

(4) During the winter season, the wind speed level reaches low value 6.5 m/s at 10 m height. This can be explained by the decrease of the temperature during winter months.
(5) An integral view of this figure gives that: since the required wind speed for a wind park is above 5 m/s [15]. And the wind is very strong at Ras Ghareb region during the whole year. So, the wind turbines will run throughout the whole year for large wind energy generation.

On the other side, the frequency distribution/histogram (the percentage frequencies of occurrence) of hourly average wind speed in meter per second are depicted in Fig. 3. This distribution of wind speed is important in determining the percentage of time during a year, the power that could be generated from a wind machine. Moreover, this information can be used to determine the amount of power which can be generated in a given speed band [16]. Hence, it indicates the wind power potential of Ras Ghareb region for wind power applications.

It can be seen from the plots that:

(1) The duration of the stillness (calm wind) as a fraction of time is zero during the year.
(2) The wind speeds in the range of 5–7 m/s have the highest frequency occurrence during the year i.e., 30%.
(3) It is further observed that: more than 54% of the time wind speed in the range from 5 to 10 m/s. This indicates that the most of the wind energy at Ras Ghareb lies in this range.
(4) It is also clear that speeds above 10 m/s occur over 19% in the whole year.
(5) Thus, the first conclusion extracted is that: most of the time 73% the mean wind speed in the ranges between 5–10 and 10–17 m/s at 10 m height. This is a strong indication that the wind potential at this region remained stable throughout the year. Hence, the wind potential at Ras Ghareb is very high and of good quality (strong enough winds of long duration).

4. Wind rose diagram

The direction of the wind is of decisive significance for the evaluation the possibilities of utilizing wind power. The direction statistics play an important role in the optimal positioning of a wind park in a given area. The wind rose shows the distribution of the wind direction in the processed time-series. Wind direction is divided in twelve 30°-sectors; the angular axis is given in degrees from 0° to 360° clockwise, the units on the radius is per cent. Moreover, the wind rose provides information about the occurrence of number of hours during which wind remained in a certain wind speed bin in a particular wind direction [17,18].

In order to construct wind rose and analyze the frequency distribution, all hourly averaged values of wind speed and wind direction were used and the resulting wind rose diagram is shown in Fig. 4. This figure depicts the wind rose chart for the station under study. Where all hourly data recorded during (2000–2005) at height 24.5 m above the ground was used for the generation of this figure. In another worth's, Fig. 4 shows remarkable variation in wind direction between the years 2000 and 2005 at Ras Ghareb station.

It is evident from this figure that:

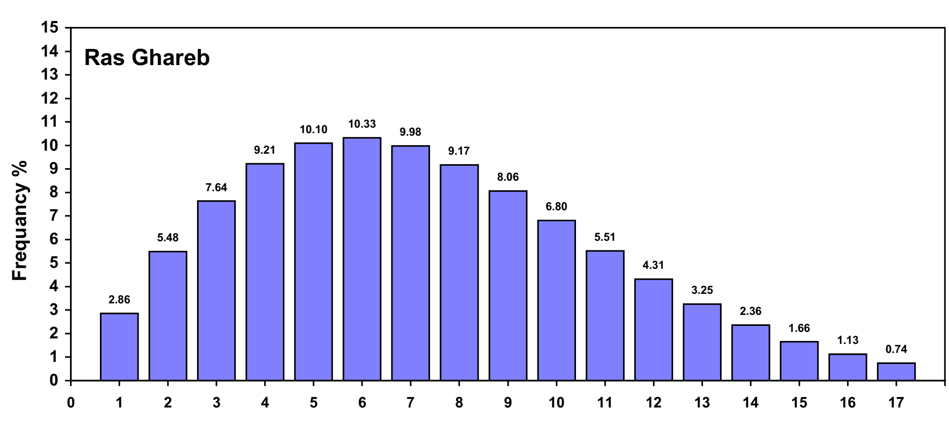

Fig. 3. Wind speed frequency at 10 m height for the average data of the years from 2000 to 2005.

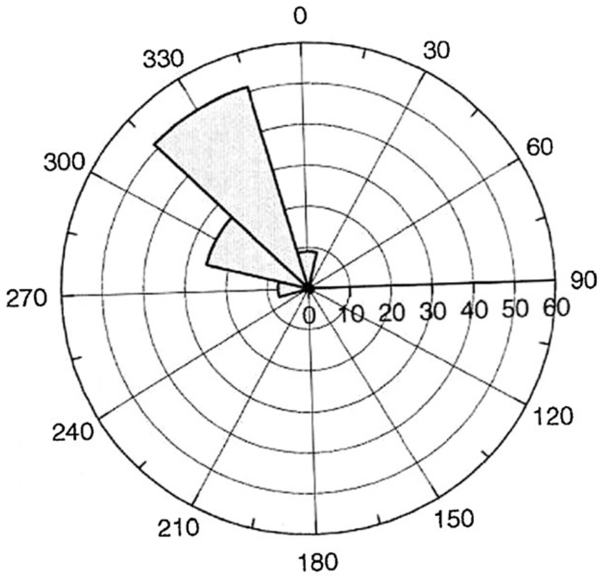

Fig. 4. Wind rose diagram for the years 2000–2005 at Ras Ghareb region at 24.5 m height.

(1) The wind blows predominantly from NNW and WNW directions for about 77% of the times. The maximum frequency of occurrence is from the north–northwest sector (330°), where the wind blows during 51% of the time with an average wind speed of around 12.6 m/s at 24.5 m.a.g.l.
(2) There were strong winds blowing from north and west sectors too. But their frequencies were quite low 9% and 7%, respectively.
(3) Hence, wind turbines can be installed against these directions for optimal energy output.

5. Power law coefficient and Weibull parameters at different heights

The calculation of the output of a wind turbine at a particular site requires knowledge of the distribution of the wind speed. Most attention has been focused on the Weibull function and the adaptation to the experimental data. Table 2 gives the Weibull parameters: seasonal shape parameter k, and scale parameter c, at different heights from 10 to 100 m. Several methods can be used for the calculation of these parameters. For simplification, they are calculated by using Justus and Mikhail equations as mentioned in our previous articles [1,2], and by using the observed data for Ras Ghareb station listed at Table 1. Also, the power law coefficient of all seasons is estimated using these equations and the results are given in Table 2. From this table we can prepare the following Table 3.

So, from Tables 2 and 3 we can see that:

(1) The values of power law coefficient, n, are low for high speeds (c_{10} or v_{10}) during the seasons: summer, spring, autumn and winter, respectively. This implication is in line with Justus's recommendation for high wind speeds ($v_{10} \geq 10$ m/s), the exponent, n, would equal about 0.15. This argument breaks down above 100 m (300 ft) [19].
(2) In general, values of the scale parameter, k, have high values throughout all seasons of the year except during winter season, where k is slightly low.
(3) This is means that during winter months of the station under study, the wind data distributed uniformly over a relatively wide wind of speeds. This is a positive point on wind power generation which leads to that Ras Ghareb region possesses enough wind speed to operate a wind turbine for at least a short period during this season.
(4) On the other hand, for large values of k observed at the three seasons (spring, summer and autumn) the majority of the wind speed data tend to fall around the mean wind speed, and for this area the mean wind speed is very high (8.3–9.9) m/s at 10 m height, then the wind would be useful for power generation for a large part of time.
(5) Finally, Ras Ghareb station at summer season has a large value of the mean wind speed (v_{10} = 9.9 m/s) and (c_{10} = 11.2 m/s) and the value of k is high. Thus, the wind speed is suitable during this period for high power generation.

Table 2
Estimated seasonal values of Weibull parameters at different heights and the power law coefficient for all seasons at Ras Ghareb.

Season	Height (m)	c (m/s)	k	Power law coefficient (n)
Winter	10	7.4	2.12	0.19
	40	9.6	2.41	
	70	10.7	2.56	
	100	11.5	2.66	
Spring	10	9.4	2.40	0.17
	40	11.9	2.73	
	70	13.1	2.90	
	100	13.9	3.01	
Summer	10	11.2	2.61	0.15
	40	13.9	2.97	
	70	15.2	3.15	
	100	16.1	3.27	
Autumn	10	9.3	2.39	0.17
	40	11.8	2.72	
	70	13.0	2.88	
	100	13.8	3.00	

Table 3
Seasonal mean wind speed, power law coefficient (n) and Weibull parameters for each season at 10 m height.

Season	V_m	n	c	k
Winter	6.5	0.19	7.4	2.12
Spring	8.3	0.17	9.4	2.40
Summer	9.9	0.15	11.2	2.61
Autumn	8.3	0.17	9.3	2.39

6. Evaluation of mean wind energy density

For most of the applications of wind power, it is more important to know the distribution of wind speed frequencies for the site under consideration. A simplified mathematical representation that accurately fitted the data, would be useful to reduce the need for data to be measured and the analytical calculation of wind machine performance could be attempted [20].

One should note that the Rayleigh distribution is a special case of Weibull distribution, which has found to typically represent the wind speed frequency distributions at most cases. In the Rayleigh distribution, the shape factor k is assumed to have a value of 2. So, the Rayleigh cumulative distribution function is expected mathematically as [21–23]:

$$R(v) = 1 - \exp\left[-\frac{\pi}{4}\left(\frac{V}{V_x}\right)^2\right] \tag{3}$$

where $R(v)$ is the Rayleigh cumulative distribution function, V_x is the long term average wind speed (m/s).

One of the most important wind characteristics is its mean energy density, where the mean power density is usuallycalculated

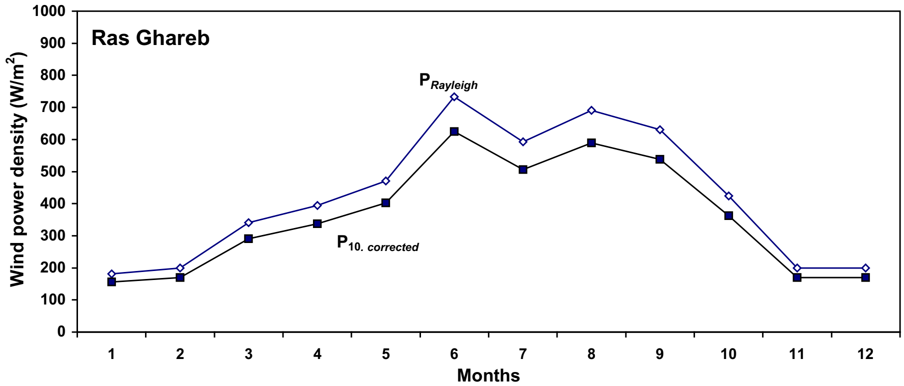

Fig. 5. Available and maximum corrected extractable monthly average wind power density by using two different methods.

by:

$$P_{\text{wind}} = \frac{1}{2}\rho V_{\text{m}}^{3}\,(\text{W/m}^2) \tag{4}$$

where ρ and V_{m}^3 are the mean air density and the mean of the wind speed cubed for a given period of time.

In case of Rayleigh distribution (i.e., $k = 2$) the following equation gives the mean speed cubed for the Rayleigh approximation [20,24]:

$$V_{\text{R}}^{3} = \frac{2}{\sqrt{\pi}}V_{\text{m}}^{3} \tag{5}$$

Hence, a simple estimating procedure can be introduced to estimate the mean power density using the Rayleigh distribution at the standard height 10 m by the following formula:

$$P_{\text{R}} = \frac{1}{\sqrt{\pi}}\rho V_{\text{m}}^{3} \tag{6}$$

On the other side, the air density is an important parameter whereas wind power calculation is concerned. The wind power density is directly proportional to the air density. Denser the air, the higher is the wind power density and vice versa [25]. Moreover, as depicted in Eq. (4) the instantaneous wind energy is related with the third power of its speed. Where $\rho = 1.225\,\text{kg/m}^3$ is the air density, which depends on the altitude (air pressure) and temperature. We make it constant for wind speeds at 10 m height and normal ambient temperature. This is due to the measurements of the temperature and pressure data that needed for the estimation of corrected air density not available at Ras Ghareb station.

In order to provide practical estimations, the calculation of the monthly corrected wind power at 10 m height – for this site which is located along the east coast of Red Sea in Egypt – can be estimated by using our equation in Refs. [3,8] (the recommended correlation equation for the wind potential on the Red Sea in Egypt):

$$P_{10} = 0.96P_{\text{wind}} + 1.4226 \tag{7}$$

Here, Eq. (7) is quite practical to evaluate P_{10}; the monthly corrected wind power for Ras Ghareb station.

In order to provide more data points for comparison, we first obtain the monthly wind power density by using Rayleigh distribution with Eq. (6). And second the monthly corrected wind power at 10 m hub height were obtained by applying Eq. (7) with wind data listed at Table 1. Then, the results of the two different methods are given in Table 4. At last, the error between them is estimated as shown in the last column of Table 4. Also, Fig. 5 is introduced. From these table and figure we can conclude that:

Table 4
Mean monthly of wind power density at 10 m, by using two different methods with error factor.

Month	P_{R} (W/m^2)	P_{10} (W/m^2)	Error (%)
Jan.	181	156	13.8
Feb.	199	170	14.6
Mar.	341	291	14.6
Apr.	395	338	14.4
May.	471	402	14.6
Jun.	733	625	14.7
Jul.	593	506	14.7
Aug.	691	589	14.8
Sep.	631	538	14.7
Oct.	424	363	14.4
Nov.	199	170	14.6
Dec.	199	170	14.6
Annual	421	360	14.5

(1) The obtained values at the two methods have the same trend and have pronounced peaks.
(2) Rayleigh model is useful tool for wind energy density estimation but not quite appropriate for fit it. Where the error obtained is higher than 10% of the actual values of the monthly corrected wind power density available at Ras Ghareb area.
(3) Hence, our method (Ahmed Shata and Hanitsch in Refs. [3,8]) is found to be a better approximation than that of Rayleigh model (i.e., it is a better fit to calculate the monthly corrected wind power available at Ras Ghareb region).
(4) However, the annual mean of wind power density at this region was 360 W/m^2 at 10 m height. Where the corrected values of P_{10}, show that the wind energy potential is very high during the months from April to October ranging from 338 to 625 W/m^2. And the highest value was 625 W/m^2 obtained during June.
(5) This means that Ras Ghareb station has a huge wind power potential available, which is twice as high as the wind potential in many countries such as Denmark, Spain, Germany, United States and India.

7. Conclusion

The conclusions derived from this study can be summarized as follows:

(1) Egypt produces electricity using wind farms at some locations located in the northern part along the Red Sea and the increase of needs exported to Jordan. Also, Egypt is looking towards the development of their wind farms in the coming time. This first preliminary study about Ras Ghareb region can be considered as the basis for further research and development of the

wind energy as a source of electricity generation at this area in Egypt. From our analysis, Ras Ghareb location, in the Gulf of Suez region, is one of the most potential sites and can be evaluated as marginal area for wind power applications.

(2) We recommend that the wind speed power law index is 0.18 and should be used to estimate the wind speed at different heights if wind measurements are available at one height for Ras Ghareb region.

(3) The wind speed at this station is generally high. The annual mean of wind speed is 8.3 m/s at 10 m height. Where the maximum value of monthly mean wind speed is 10.2 m/s during June and the minimum value was 6.4 m/s during January. On the seasonal scale: Ras Ghareb's wind climate is characterized by the trade winds during summer season in the range of 10 m/s.

(4) The frequency analysis assures the availability of wind above 5 m/s for 54% of the time during the entire year at 10 m above the ground surface. At 24.5 m above the ground surface, the availability of the wind above 12.6 m/s is assured for 51% of the time. Hence, the wind potential at Ras Ghareb is very high and of good quality (strong enough winds of long duration).

(5) The wind blows predominantly from NNW and WNW directions for about 77% of the time over the year. Then, wind turbines can be installed against these directions for optimal energy output.

(6) Investigations of Weibull parameters indicate that: scale parameter, k, has high values during all seasons of the year except at winter period, it is slightly low. Thus the majority of the wind speed data tend to fall around the mean wind speed, and for this region the seasonal mean wind speed is very high (8.3–9.9) m/s at 10 m. So, the wind would be useful for large power generation at a large part of time over the year.

(7) Rayleigh distribution is useful tool for wind energy density estimation but not quite appropriate for fit it. Where the obtained error is higher than 10% of the actual values at Ras Ghareb station. And our method (Ahmed Shata and Hanitsch in Refs. [3,8]) is found to be better than that of Rayleigh model to calculate the monthly corrected wind power available at Ras Ghareb region.

(8) This site has very high wind power density during the months from April to October ranging from 338 to 625 W/m^2. Where the mean wind power potential available from the wind at this area can reach more than 360 W/m^2 annually at 10 m height. And the highest value was 625 W/m^2 recorded during June. Ras Ghareb area along the Red Sea in Egypt is comparable to and sometimes higher than the power density in European countries, America and Canada. Hence, this location can be explored for electricity generation.

References

[1] Ahmed Shata A. Wind energy as a potential generation source at Ras Benas, Egypt. Renewable and Sustainable Energy Reviews 2010;14:2167–73.

[2] Ahmed Shata AS, Hanitsch R. Applications of electricity generation on the western coast of the Mediterranean Sea in Egypt. International Journal of Ambient Energy 2008;29(1):35–44.

[3] Ahmed Shata AS, Hanitsch R. The potential of electricity generation on the east coast of Red Sea in Egypt. Renewable Energy 2006;31:1597–615.

[4] Mortensen NG, Youssef LG. Wind atlas for Egypt. Measurements and modeling 1991–2005. Cario, Roskilde: Risø National Laboratory, Roskilde/New and Renewable Energy Authority/Egyptian Meteorological Authority; 2005, ISBN 87-550-3493-4.

[5] Adekoya LO, Adewale AA. Wind energy potential of Nigeria. Renewable Energy 1992;2(1):35–9.

[6] Pimenta F, Kempton W, Garvine R. Combining meteorological stations and satellite data to evaluate the offshore wind power resource of Southeastern Brazil. Renewable Energy 2008;33:2375–87.

[7] Ettoumi FY, Adane A, Benzaoui ML, Bouzergui N. Comparative simulation of wind park design and siting in Algeria. Renewable Energy 2008;33:2333–8.

[8] Ahmed Shata AS. Theoretical investigation and mathematical modelling of a wind energy system – case study for Mediterranean and Red Sea. Ph.D. thesis submitted to Faculty of Electrical Engineering and Computer Science, Berlin University of Technology, Germany; June 2008.

[9] Jaramillo OA, Salaña R, Miranda U. Wind power potential of Baja California Sur, México. Renewable Energy 2004;29:2087–100.

[10] Shabbaneh R, Hasan A. Wind energy potential in Palestine. Renewable Energy 1997;11(4):479–83.

[11] Sedefian L. On the vertical extrapolation of mean wind power density. Journal of Applied Meteorology 1980;19:488–93.

[12] Poje D, Cividini B. Assessment of wind energy potential in Croatia. Solar Energy 1988;41(6):543–54.

[13] Coelingh JP, van Wijk AJM, Holtslag AAM. Analysis of wind speed observations over the North Sea. Journal of Wind Engineering and Industrial Aerodynamics 1996;61:51–69.

[14] Carta JA, Ramírez P, Velázquez S. A review of wind speed probability distributions used in wind energy analysis. Case studies in the Canary Islands. Renewable and Sustainable Energy Reviews 2009;13:933–55.

[15] Alnaser WE, Al-Karaghouli A. Wind availability and its power utility for electricity production in Bahrain. Renewable Energy 2000;21:247–54.

[16] Rehman S. Wind energy resources assessment for Yanbo, Saudi Arabia. Energy Conversion and Management 2004;45:2019–32.

[17] Bilgili M, Sahin B, Kahraman A. Wind energy potential in Antakya and İkenderun regions, Turkey. Renewable Energy 2004;2:1733–45.

[18] Al-Abbadi NM. Wind energy resource assessment for five locations in Saudi Arabia. Renewable Energy 2005;30:1489–99.

[19] Corotis RB, Sigl AB, Klein J. Probability models of wind velocity magnitude and persistence. Solar Energy 1978;20:483–93.

[20] Algifri AH. Wind energy potential in Aden-Yemen. Renewable Energy 1998;13(2):255–60.

[21] Lysen H. Introduction to wind energy. 2nd edition The Netherlands: Consultancy Services, Wind Energy, Developing Countries (CWD), 82-1; 1983. pp. 36–47.

[22] Mathew S, Pandey KP, Anil Kumar V. Analysis of wind regimes for energy estimation. Renewable Energy 2002;25:381–99.

[23] Ilinca A, McCarthy E, Chaumel J-L, Rétiveau J-L. Wind potential assessment of Quebec province. Renewable Energy 2003;28:1881–97.

[24] Jamil M, Parsa S, Majidi M. Wind power statistics and an evaluation of wind energy density. Renewable Energy 1995;6(5/6):623–8.

[25] Rehman S, Al-Abbadi NM. Wind shear coefficients and energy yield for Dhahran, Saudi Arabia. Renewable Energy 2007;32:738–49.